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Internet of Things Based System for Cucurbitaceous Crops Farming

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Abstract: The current food shortages due to increasing population, especially in developing countries calls for intensification of efforts in the development and adoption of technologies to enhance food production. Soil type and quality is key for crops to grow produce maximally, hence the soil should be properly managed. This is where technology involvement becomes necessary. Smart agriculture using Internet of Things (IoT) system can help farmers to analyse soil properties, monitor and control crops intake of vital nutrients. This research developed a more cost effective Online IoT-based technology for soil testing, analysing soils for better nutrient advisory to cucurbitaceous farmers. The research adopted an experimental method and used the object oriented analysis and design methodology. An IoT based system with Arduino Uno, ESP8266 Node Microcontroller and NPK sensors was developed and used to collect and analyse soil data. The system when deployed will assist farmers to test soil type and nutrient qualities in real/offline time and receive experts advice on cucurbitaceous crops in order to increase crop quality and yields.

Keywords: Cucurbitaceous crops, Internet of Things, Agriculture, Soil nutrient, Farming

I. Introduction

There is food insecurity in many developing countries that calls innovative solutions. Innovative solutions have become imperative as the global population continue to rise, coupled with many disruptive factors that impinge crop production and yields. Thus, new and sustainable agricultural technologies should be developed and adopted to check the rising food shortages in many countries [1].

Over the years, farmers especially in developing countries depend mostly on traditional knowledge gained through experience and shared over many generations in carrying on their farming activities. This practice adversely affects crop production and yield, and cannot reduce the over-dependency on food importation and hunger, in these countries. For instance Nigeria is not producing enough cucurbitaceous crops to meet the recent upsurge in demand due to increased awareness of their health benefits. This is majorly is due to wrong perceptions and lack/low utilization of supportive technologies, poor access to expert knowledge on farming methods, high labour, and input costs.

A country's ability to fully exploit its agricultural production potential depends on the innovativeness of actors in the agricultural sector, particularly farmers. The wiliness of farmers and actors to adopt new technologies in agricultural production activities is contingent on the availability, cost and ease of use of technology [2].

Against popular believe, studies have shown that Cucurbitaceous can do well in both the Northern and Southern parts of Nigeria. Currently the Southern states are heavily dependent on the North states which currently produce about 80% of Cucurbitaceous crops consumed in the country [3], [4]. With various factors negatively affecting agricultural activities in many parts of the country, especially in the North, there is need to encourage more people especially in the Southern States to engage in cultivation of cucurbitaceous crops (cucumber, melon, watermelon, pumpkins, squash, etc.).

Cucurbitaceous farming is a money-spinner due to increased consumption. For instance Watermelon in the worst-case scenarios the profit is N765,000, and the best case one can make N6.77 million, per hectare of cultivated land. Fertilizer and pesticides constitute about 60% of the production expenses, but the exact quantity needed can rightly be estimated after complete soil analysis [5].

Nigeria has over 70.8 million hectares of arable land, which should be the foundation of its economy. But due primitive agricultural practices: low use of mechanization, poor agriculture extension services, poor quality inputs, poor infrastructure, uncontrolled climate change, high production cost, etc., the countries is heavily food import-dependent [6], [7], [8].

According to [9], Nigeria agricultural sector employed over 70% of the population, contributed 32% as foreign exchange earnings, provided 28% of raw materials, about 24.45% to the total Gross Domestic Product.in in 2020 [10].

Cucurbits are warm season crops. The optimum temperature for growth is about 30oC - 35oC and night temperature is 18-20oC. The soil should be fertile and rich in organic matter with a soil pH ranging from 6.5 to 7.5. They are popular fruit for fresh consumption and agro-processing, such as juice making. It contains some of the most important antioxidants in nature- e.g. Lycopen. [10].

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For farmers in Nigeria, Cucurbits are best planted in the Southern part between mid-March and April-ending and in the Northern part, mid-May for early season and late August for late season. However, with functional irrigation the crop could be planted in the north all year round.

Cucurbits belong to the family Cucurbitaceous; it is an important and a large group of vegetables that can grow in many tropical and sub-tropical regions of the world. The fruits of cucurbits are consumed fresh as a dessert or in salads (cucumber and long melon); cooked (bottle gourd, bitter gourd, sponge gourd, ridge gourd, summer squash, squash melon, pumpkin etc.) and processed in pickles (pickling cucumber, pointed gourd), jam (pumpkin) or candied (ash gourd). Most of the cucurbits are annuals, directly sown and propagated through seed. Most of the cultivated forms of cucumber are monoecious but some gynoecious (purely female) lines have been developed for their use in hybrid seed production. Cucurbits are insect pollinated usually honeybees. If insect activity is poor, the fruit yield is also low due to poor fruit setting. In commercial plantings, honeybee colonies are therefore introduced to enhance pollination [11].

Soil is an essential source of nutrients for plant growth. Nitrogen (N), phosphorus (P), and potassium (K) (NPK) are key nutrients; others such as Calcium, magnesium, and sulphur are essential nutrients including trace elements iron, manganese, zinc, copper, boron, and molybdenum. However, nutrient intake by crops depends on the available minerals in the soil. To determine the right soil for any crop, requires measurement of nutrients in the soil [12].

Soil testing is conducted to analyse its status in terms of fertility. The testing plays an important role in prediction of required nutrients of the crops like especially properties Nitrogen, Potassium and Phosphorus {NPK). The measurement of NPK levels of soil is vital to make a decision additional quantities required to for crops and at different growth stages. An enhance soil usually impact the overall productivity of crops. Researchers are looking for ways to optimize plant yield while minimizing the consumption of fertilizer. Research have shown that environment monitoring and controlling, play key role in effective and efficient crop production [13], [14]. Hence the need for smart technologies such as the IoT. IoT describe physical objects embedded with sensors, software, processing ability and other technologies that connect and exchange data with other systems over the internet. It plays key roles in many endeavours, and it is gaining the attention of researchers in the field of agriculture.

Research on smart IoT operation is increasing as the technology advances. IOT systems are used to monitor and control environmental factors, collect, analyse data such as temperature, humidity, pH, moisture, macro/micro nutrients, soil type, and disease, determine fertilizer application at different stages of cucurbits for optimum yield [15].

A smart IoT service system can receive inputs from its environment, uses the data collected to detect the condition, and interact with the user environments and provide solution to challenges [16]. Many studies have been conducted on innovation and adoption of new technologies and the impact of adopting new technology in developing countries. Reports show that new agricultural technologies are often adopted slowly and several aspects of adoption remain poorly understood [17]. Some studies have identified the high cost of IoT devices, limited internet access and low technical knowledge among farmers as barriers to the widespread adoption of IoT applications. The study emphasized the need for both government and private sectors to intervene by subsidizing technology adoption and providing the necessary infrastructure support [18].

Fertilizer management according [19] is one of the major cost components. The study recommended appropriate testing and soil analysis to ensure efficient use. Hence the goal of this IoT-base technology which aimed to provide improve the current practices, by making connectivity available anytime with anything, anywhere. The IoT wide application has led to its deployment in various automations; home, agriculture and monitoring heavy machinery, transportation, electricity, energy, appliances, smartphones, etc., [20].

The IoT based system develop in this research, is a web application; thus the ownership of the system is not mandatory. It assists especially, cucurbitaceous crop farmers, in determining soil quality at any growth stage, right temperature, humidity, quality/quantities of NPK required, and provides access to information via a pool of agricultural expert, extension workers and agricultural agencies, who registers with the system. The system offers both real time and offline soil data testing and analyses, and has the potential to contribute data to agriculture database when the system is deployed, which can serve as a knowledgebase for researchers and advisory purposes.

II. Literature Review

Acceptable fertilization of cucurbits has several advantages in growth and seedling strength; there are many evidence in literature that these crops can repair various nutritional stresses. However it is important decisions to consider the sources of fertilizer to be used, when to apply and the right quantities. Crops fertilizer requirement of fertilizer vary according to the type of cultivation. In open field condition, the application involves a basic dose before sowing the seeds and during cultivation, whereas continuous application of fertilizers is advised under protected cultivation system [21]. Farmyard manure should be incorporated in the field 3-4 weeks before sowing at the time of field preparation. Full dose of phosphorus, potash and half dose of nitrogen is recommended as basal dose at the time of sowing, while the rest ⅔ dose of nitrogen is applied in furrows in standing crop in two equal instalments at 30 days after sowing and at flowering time [22]. This study provided a guide on Seed rate, temperature and duration for germination of various cucurbits as given in table I, while table II is on fertilizer application by Jyoti and Jatinder [21].

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Table I. Seed Rate, Duration and Temperature for Germination of Cucurbits

Cucurbit Crop	Seed Rate (Kg/ha)	Req Temp (oC)	Days for germination
Bottle gourd	4-5	20-30	5
Bitter gourd	5-6	28-30	5
Cucumber	2-3	28-30	5
Round gourd	5-6	29-32	3
Muskmelon	3-4	28-32	3
Watermelon	45	26-28	4
Ridge gourd & Ash gourd	4-5	26-28	4

Table II. Input survey report for cucurbits

Cucurbit Crop	CA (ha}	Fertilizers used area (ha)				
		CF	FYM	OC	organic	GM
Bottle gourd	5296	3967	1917	104	189	187
Bitter gourd	1818	768	700	57	36	30
Cucumber	356	124	51	21	25	5
Round gourd	1287	354	1013	1	42	3
Muskmelon	89	39	53	0	0	0
Watermelon	798	591	96	0	0	0
Ridge & Ash gourd	785	706	373	0	2	5

CA= Crop Area, CF= Chemical Fertilizer, FYM=Farm Yard Manure, OC = Oil Cake, GM = Green Manure

According to Seminis [23] nitrogen is the most common nutrient problem for water melon production; it's deficiency at any time during the season can affect crop yield and quality and deficiency when fruit size is between 4-6 inch in diameter is damaging. It also provide recommendation on Nitrogen application at various growth stages that was based on tissue analysis; 3-4 leaves, early runner, 2-inch melon and Full-sized melons. Lyocks et al conducted experiments aimed at determining the appropriate planting date and nitrogen rate for optimum watermelon yield, quality and realisable revenue, it show effects of planting dates and varying nitrogen levels on quality, yield and gross margins of watermelon. Lyocksi et al affirmed also that nitrogen deficiencies at any time during the season can affect crop yield and qual i ty, and deficiencies when frui t size ranges from 4 to 6 inches in diameter can be the most damaging. Excess N can promote vegetative growth at the expense of flowering and fruiting, thereby decreasing the soluble solids content [24]

Research and extension services in many countries are face the challenge how to increase output from their country's agricultural sector while sustaining and improving the productive potential of the available natural resources. Few developing countries have the financial resources required to widely promote good soil management, through the traditional means of government extension services, required to achieve food security [22].

Thus a number of systems have been developed to assist farmers to analyse soil and nutrient, and provide expert advice, which ordinarily require engaging human-experts to make informed decisions for higher productivity. Kassim & Abdullah, [25]

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developed an advisory system, which focused on soil fertility management. The system enables farmers to know the environmental factors like temperature and humidity that affect crops, and exchange information between end-users.

[26], developed a smart phone application system to control environmental factors that affect crops using data mining and IoT sensors. The system predicts suitable temperature, humidity, and moisture for crops but does not monitor nor predicts soil nutrients such as Nitrogen, Phosphorous and potassium (NPK).

Akhil et al, [27], developed a system that used Fibre Optic sensor, pH / moisture sensor and GSM (Global System for Mobile Communications) connected to the Arduino microcontroller for field data collection which detects soil nutrients. However, the Fibre optic sensor causes delay making the system not to act in real time.

[15], proposed an IoT-based system for soil nutrients and suitable crops detection using soil test kit, colour sensor, pH sensor, and DHT11 sensor. The suitable crop is determined after comparing the collected data with NPK values of crops in their database. However the farmer is required to take sample of the soil and blend the soil sample with water before the sensors can detect the soil nutrients.

Brindha et al, [29], proposed a mobile IoT system to manage fertilizer usage. The system uses the value from NPK sensor to determine the right quantities required for various crops. However, it does not consider environmental factors such as the temperature and the humidity.

[30], developed a system that used combination of sensors to collect data on temperature, humidity, and moisture of soils. Arduino microcontroller was used to interconnection the different sensors but the system did not monitor soil nutrients.

Findings from literatures reviewed, show that the majority of the systems focused on the application of IoT on variables such as climatic factors, environmental factors and human activities. However, none of the systems prescribe the quantity of nutrients to be required at different growth stages of cucurbits and expert advice on other issues. And, some of the systems still require the farmer to augment the system output with his experience to make decisions.

III. Methodology

The research adopted the experimental method. The system analysis and design followed the Object Oriented and Analysis Design (OOAD) methodology and the Unified Modelling Language (UML) techniques. The system is composed of interconnected sensors on Arduino Uno R3 board to collect soil samples data from some communities in the five states in the South Eastern Nigeria. The system analyses soil to ascertain its nutrient for suitability of cucurbits at different growth stages. Some data were collected/analyse real time, while some was offline; pre-processed and feed into the system for analysis.

The following sensors were used to collect the primary soil data

- Soil NPK sensors was used to collect the NPK value of the soil samples, while the Max485 TTL to RS-485 was used to convert the electrical signal between the NPK sensor and the Arduino Uno
- The Arduino Uno R3 board ATmega328p ATmega16u2 microcontroller chip was used to interconnect sensors and WIFI device module.
- A DHT11 sensor was used to collect data on temperature and humidity of the soil sample.
- The ESP8266 Node Micro Controller Unit MCU was used as a WI-FI hotspot to transfer the data collected by the sensors to the data server

The IoT based sensors were setup and configure at a computer lab for the soil data analysis.

The Block diagram of the system is shown in figure 1a while figure 1b shows the IoT and system design.

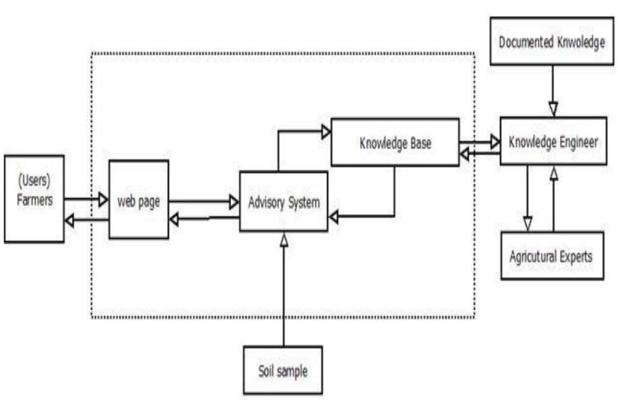

Fig. 1a:Block diagram of the system

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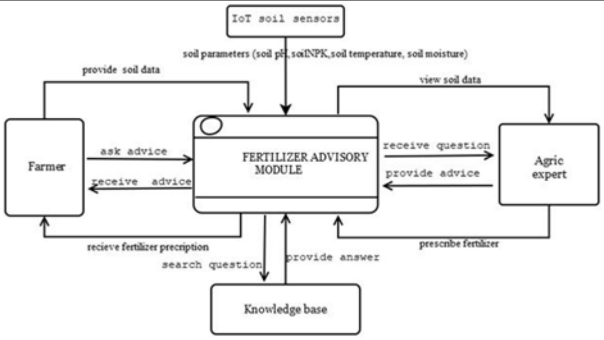


Fig. 1b The Context diagram of the system

The main system entities and the roles are shown in the use case diagram of figure 2, these include the Farmer, Agricultural Expert, Soil and NPK sensors.

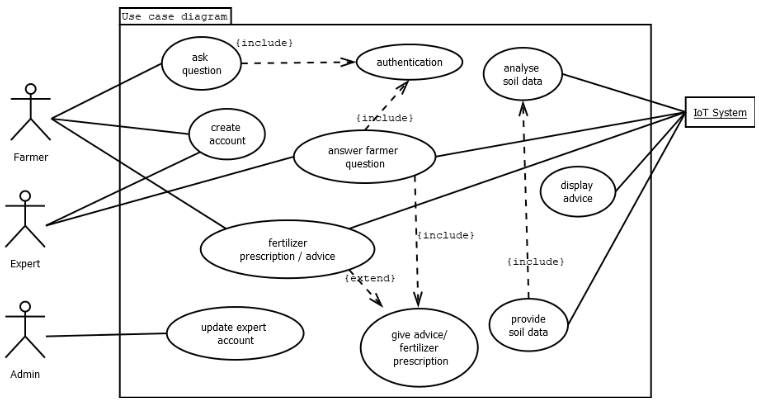


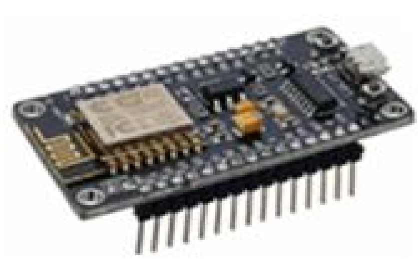
Fig. 2 The System Use Case diagram

The System Hardware Components

The system the hardware components include Arduino Uno R3 board ATmega328P shown in figure 3. It is a simple microcontroller chip based on the ATmega328P. It is an open-source physical computing platform for creating interactive objects that can stand alone or collaborate with software in a computer [28]. It enables communication between the computer and other microcontrollers, and was used to interconnect sensors and a WIFI device module.

Fig. 3 Arduino Uno R3 board ATmega328P

The ESP8266 node microcontroller unit in figure 4 was used as a WI-FI hotspot to transfer the data collected by the sensors to the system database. It is an open-source firmware and development board used in IoT based applications..



Fig, 4 ESP8266 Node MCU

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Figure 5 is the Soil NPK sensor used to measure the NPK value of the soil, and Figure 6 is the MAX485 TTL to RS-485 Interface Module used to send and receive data through the RS-485 network from the Arduino micro controller; it converts the signal between the NPK sensor and the Arduino Uno into a usable format. The device has two 4-pin headers and supports signal for robust long-distance serial communications of up to 1200 meters at about 2.5Mbit/Sec, data rates to up to 32 devices on the same bus and operate at 5V.

Fig. 5 NPK Sensor

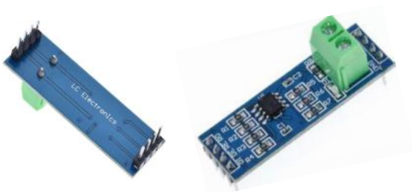

Fig. 6 MAX485 TTL to RS-485 Interface Module.

Figure 7 is the digital temperature and humidity DHT11 sensor used to collect soil temperatures and humidity data.

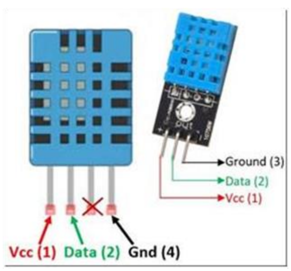

Fig. 7 DHT11 Temperature-Sensor .

The schematic diagram of the system is in figure 8.

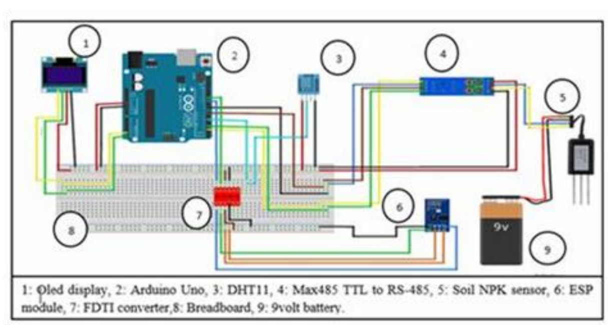

Fig. 8 Schematic diagram of the hardware components.

The System Software Componenst

The software component comprises of a three-tier architecture; the presentation layer or user side (web pages), data layer and the data server side.

- The presentation side was designed using JinJa2, HTML5 and CSS3.
- The middle tier was implemented with Python3 framework to mediate between the presentation layer and the data layer.
- MySQL database management system is the data-server; used to store and manage the system data.

Python Flask framework was used to create the user side of the software. Data collected using the IoT devices were sent to the database (server side). The nutrients, temperature requirements of Cucurbitaceous during the life cycle and other necessary data were extracted from literature, especially (SHEP PLUS, 2019) and form part of this system database. The values were used for comparisons and to facilitate prescription. The system architecture is a Three-tier (3-Tier) as shown in figure 9.

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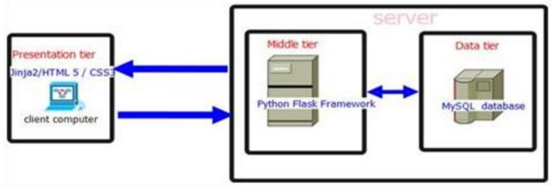

Fig. 9 The System Architecture.

Fig. 10a The Form for Asking questions (Advice)

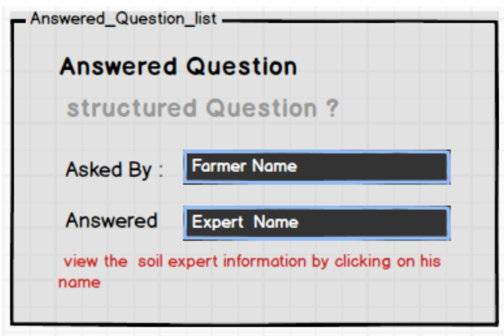

Fig. 10b The Response to Question

Example of the Algorithm for Soil properties Advisory on Watermelon

Let FI = the farmer information (Flogin = farmer login, Fpass = Farmer password).
Let EI = the Agricultural Expert information (Elogin = Expert login, Epass = Expert password).
Let D_{FI} = Farmer Data into the database
Let D_{EI} = Expert Data into the database
Let $Quest^{Far}$ = the farmer question.
Let $Answ^{exp}$ = Expert answer.
Let $Agric^{lists}$ = list of Expert
Let $Farm^{queslist}$ = Farmer question.
Let $Soil_N$ = Nitrogen Value from IoT devices.
Let $Soil_p$ = Phosphorus value from Iot devices.
Let $Soil_K$ = Potassium value by the devices.
Let $Soil^{type}$ = Soil. type
Let $Temp^{soil}$ = Temperature value by the IoT devices.
Let Hum^{soil} = Humidity value collected by the IoT devices.
Let pH^{soil} = pH value.
Let $Text^{soil}$ = Soil texture.
Let Nbr^{day} = Number of days / weeks after planting.

- String Ask_question (string Flogin, string Fpass)
- Read Flogin,

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- Read Fpass
- Determine Ask_question
- if D_{FI} # FI THEN

create an account
”
ELSE

- Ask_question = $Quest^{Far}$
- $Agric^{lists}$ = experts
- Display Fig 10a: Farmer Ask question
- String Answer_question (string Elogin, string Epass)

Read Elogin
Read Epass

3. Determine answer_question

- IF EI # D_{EI} AND Elogin # $Agric^{lists}$ THEN
- “create an account”

ELSE

for each Question in $Farm^{queslist}$

IF $Farm^{queslist}$ is not null THEN

answer_question = $Answ^{exp}$

ELSE

answer_question = “null”

Display Fig 10b: Answer farmer question

- String soil-pre-requirement (string $Soil^{type}$, int $Temp^{soil}$, int Hum^{soil}, int pH^{soil}, int $Text^{soil}$)

Read $Soil^{type}$,
Read $Temp^{soil}$,
Read Hum^{soil},
Read pH^{soil},
Read $Text^{soil}$
Determine pre-requirement
IF (pH^{soil} < 6 OR pH^{soil} > 6.8) AND ($Temp^{soil}$ < 22 OR $Temp^{soil}$ >36) AND ($Soil^{type}$ # sandy_loam OR $Soil^{type}$ = Saline-soil OR $Soil^{type}$ = Clay-soil) AND ($Text^{soil}$ # Light-texture) AND (Hum^{soil} = cold) THEN
soil-pre-requirement = ‘’ the plant is not in the required condition to growth’’

ELSE

soil-pre-requirement = “valid soil requirement”
Display: Fig 13: Fertilizer prescription

- Int soil_nitrogen_prescription (int Nbr^{day}, int $Soil_N$)

Read Data
Read Nbr^{day}
Read $Soil_N$
Determine the soil_nitrogen_prescription
IF Nbr^{day} == 0 THEN // pre-sowing period (2 to 3 weeks)

IF $Soil_N$ < = 180 THEN

soil_nitrogen_prescription = 180 - $Soil_N$
IF Nbr^{day} == 25 THEN // sowing period (2 to 3 weeks after sowing)
IF $Soil_N$ < = 180/3 THEN
soil_nitrogen_prescription = 180/3 - $Soil_N$
ELSE
IF Nbr^{day} == 35 OR Nbr^{day} <= 60 THEN // vegetative and flowing stage
IF $Soil_N$ < = 90 THEN

soil_nitrogen_prescription = 90 - $Soil_N$

DISPLAY Fig 13: Fertilizer prescription

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- Int soil_phosphorus_prescription (int Nbr^{day}, int $Soil_P$)

Read Data
Read Nbr^{day}
Read $Soil_p$
Determine the soil_phosphorus_prescription

IF Nbr^{day} == 0 THEN //pre-sowing

IF $Soil_p$ < = 168 THEN
soil_phosphorus_prescription = 168 - $Soil_p$

ELSE

IF Nbr^{day} >= 84 OR Nbr^{day} <= 14 THEN // after planting

IF $Soil_p$ < = 168 THEN
soil_phosphorus_prescription = 168 - $Soil_p$ // the value of P should be stable

ELSE

"the value of P should be stable"

DISPLAY Fig 13: Fertilizer prescription to farmer

- Int soil_potassium_prescription (int Nbr^{day}, int $Soil_K$)

Read Data
Read Nbr^{day}
Read $Soil_K$
Determine the soil_potassium_prescription

IF Nbr^{day} == 0 THEN //pre-sowing

IF $Soil_K$ < = 168 THEN
soil_potassium_prescription = 168 - $Soil_p$

ELSE

IF Nbr^{day} >= 84 OR Nbr^{day} <= 14 THEN // after planting

IF $Soil_K$ < = 168 THEN
soil_potassium_prescription = 168 - $Soil_p$ // the value of K should be stable

ELSE

soil_potassium_prescription = "the value of P should be stable"

DISPLAY Fig 13: Fertilizer prescription

IV. Results and Discussions

The screenshots below show some of the system outputs. figure 11 is the system home page; the dashboard for all activities of the system while figure 12 is a sample of the soil data received from the input sensors in real time. Otherwise, in areas with poor network, the sensor readings may be collected and entered by the farmer/user when/where network communication becomes available possibly off the farm site.

Fig. 11 The System home page

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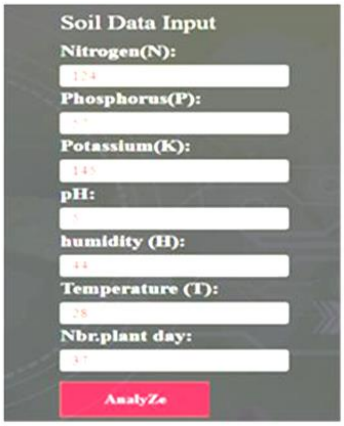

Fig. 12 Soil data from the Input sensors

Figure 13, presents a specific fertilizer recommendation at a given growth stage of the Cucurbitaceous. The prescription may be saved for future references. A farmer may through the system interact with agro experts and receive a feedback such as the one in Figure 14.

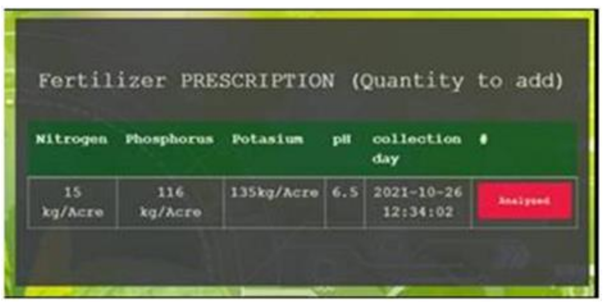

Fig. 13 Fertilizer prescription to farmer

Fig. 14 The Home-Page General Feedback to Farmers questions

V. Summary & Conclusion

The increased awareness of the health benefits of Cucurbitaceous has caused significant increase in its demand and price of Cucurbitaceous. The study show that these crops can grow in many communities in South East Nigeria and farmers have huge potential to improve their wealth by embarking on and improving the production of Cucurbitaceous.

This study developed a system that assists farmers to improve Cucurbitaceous production using IoT based sensors to test, analyse farm soils. The system focus was for Cucurbitaceous crops; however, the case study was on Watermelon. The system is useful for all kinds of soil analysis, thus useful to most farmers. It enables after analysis soil data; the prescription of the right quantities of Nitrogen (N), Phosphorus (P) and Potassium (K) to be applied at various growth stages of Cucurbitaceous.

The goal was to provide a handy IoT based tool that does not require laboratory or ownership so as to reduce expenditure on soil and fertilizer tests, times/energy requirements in order to increase productivity. The System also provides efficient, user-friendly and effective communication between the farmer and agriculture experts.

This research is still ongoing and proposes to implement a machine-learning model that predicts Cucurbitaceous yields and disease management.

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